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TNO report

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Endgame analyses against a ballistic missile: a parametric study

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Analyses tijdens de eindfase van ballistische raketten: een parmetrische studie

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Probleemstelling

Eén van de problemen bij de onderschepping van Tactical Ballistic Missiles (TBMs) is de hoge relatieve snelheid tussen de interceptor en de TBM. Dit vereist speciale aandacht voor het juiste springpunt indien een interceptor met een fragmentatiegevechtslading wordt ingezet om de TBM te onderscheppen. De letaliteit van een dergelijke gevechtslading tegen een TBM wordt vergeleken met de letaliteit van een zogenaamde hit-to-kill interceptor. Een ander probleem is het effect op de grond, dat wordt veroorzaakt door restanten van de gevechtslading van de TBM na onder-schepping. Ook hieraan wordt in dit rapport aandacht besteed. In het kader van het TMD-programma, V004, is binnen TNO Defensie en Veiligheid kennis opgebouwd op bovengenoemde gebieden die in dit rapport wordt beschreven.

Beschrijving van de werkzaamheden

Aan de hand van beschikbare theoretische modellen is een gevoeligheidsanalyse uitgevoerd van parameters die cruciaal zijn voor het juiste springpunt van een fragementatiegevechtslading tegen een TBM. Vervolgens is een dergelijke gevoeligheidsanalyse uitgevoerd, tegen TBM die met een hit-to-kill interceptor wordt onderschept. Indien de gevechts-lading van een TBM submunities bevat, wordt het aantal vernietigde submunities als maatstaf gehanteerd om een vergelijk te maken tussen de letaliteit van een fragmentatiegevechtslading en een hit-to-kill interceptor. Tenslotte is gekeken naar de effecten op de grond die worden onderschepping hebben overleefd. Hiervoor is aangenomen dat de submunities chemische agens bevatten, die op de grond worden verspreid. Het oppervlak dat op de grond met een zekere concentratie van de agens wordt besmet, wordt als maatgevend beschouwd voor de letaliteit tegen onbeschermd personeel.

Resultaten en conclusies

De uitkomsten van deze studie laten zien dat een hit-to-kill interceptor meer submunities vernietigt dan een interceptor met een conventionele framentatie-gevechtslading, zelfs als het springpunt optimaal wordt gekozen. De gebruikte modellen in deze studie hebben hun beperkingen met betrekking tot het snelheidsgebied waarin de modellen mogen worden gebruikt. Daarnaast kunnen secundaire schade-effecten aan submunities, ten gevolge van hydraulic ram, secundaire verscherving (spall) of blast, niet met deze modellen worden gesimuleerd, waardoor de letaliteitsuitkomsten wellicht te pessimistisch worden voorgesteld. Teneinde hierover zekerheid te krijgen,

dienen meer geavanceerde modellen te worden toegepast. Eén van de opties is het gebruik van de computercode PEELS (Parametric Endo/Exo atmospheric Lethality Simulation) uit de VS. De code is gebaseerd op theorie aangevuld met resultaten afkomstig uit vele series experimenten die in de VS zijn uitgevoerd op het gebied van penetratie van scherven en projectielen op TBM-gevechtsladingen onder zeer hoge trefsnelheden. Na een zeer langdurig proces, heeft TNO toestemming van de Amerikaanse overheid gekregen om de code te mogen gebruiken. In december 2003 is de code ontvangen.

Toepasbaarheid

Het in dit rapport beschreven onderzoek kan worden gebruikt om een indruk te krijgen omtrent de letaliteit van interceptors tegen TBMs met een dracht en een snelheidsverloop die vergelijkbaar zijn met de Scud missile.

Validatie

Als vervolg op deze studie zal ervaring worden opgedaan met de code PEELS waarna de situaties die in dit rapport zijn beschreven met deze code worden nagebootst. Op deze wijze wordt hopelijk meer inzicht verkregen in de geldigheid van de aannames die in deze studie zijn gemaakt.

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Frequentie van overleg Met de programmaleider werd circa tweemaandelijks gesproken over de invulling en de voortgang van het onderzoek.	Projectteam ir. P.W. Doup en ir. W. Haverdings

Contents

1 Introduction

This report describes the activities which were conducted during the years 2002 and 2003, within the project 'Endgame Analyses', which is part of the Programme 'Active Defense against Ballistic Missiles'. 'Endgame Analyses' concentrates on lethality related aspects of interceptors against warheads of ballistic missiles.
Engagements between interceptors and ballistic missiles occur under very high velocities (kilometers per seconds). Therefore, a literature survey was conducted concerning penetration relationships of fragments and projectiles during hypervelocity impact conditions. The findings of this survey have been reported in [1]. Off all the various theoretical models described in [1], only the so-called THOR penetration relationships are available at TNO. The equations describing these relationships, are only valid for the lower impact velocity spectrum (less than approximately 3 km/s).
This report addresses the lethality of interceptors with fragmentation warheads against ballistic missiles. Due to the impact velocity limitation within the THOR equations, the engagement conditions were chosen such, that the application of these equations remain valid. The lethality results have been compared with those of a so-called hit-to-kill (HTK) interceptor, where the kinetic energy of the interceptor itself is used as a lethality mechanism during impact on the ballistic missile. The chosen intercept conditions in this report are representative for low endo-atmospheric interceptors against a Scud-like threat.
The ballistic missiles considered in this report, are assumed to contain sub-munitions filled with chemical agent. For the purpose of comparison, the lethality results have been expressed in percentages destructed sub-munitions by either a fragmentation warhead, or a HTK interceptor. Next, the effects on the ground were considered, caused by the sub-munitions which survived the impact, expressed in contaminated areas by the chemical agent.
Chapter 2 of this report, addresses a number of critical parameters which determine the lethality of fragmentation warheads, while Chapter 3 summarizes these kind of parameters for HTK interceptors. The lethality analysis is described in Chapter 4 (fragmentation warhead) and Chapter 5 (HTK-interceptor), respectively. Chapter 6 mentions some possible improvements to increase the lethality. Chapter 7 addresses the effects on the ground, caused by the surviving sub-munitions. Finally, Chapter 8 summarizes the conclusions of this study.

2 Fragmentation Warheads

The success of defeating the payload of a TBM by using a fragmentation warhead, strongly depends on a number of parameters and their relationships, such as:

- Miss-distance between interceptor and TBM;
- Velocities of interceptor and TBM;
- Lean angle of the fuse;
- Moment of detonating the fragmentation warhead after detection by the fuse (time delay);
- Dispersion angles of the fragment spray;
- Penetration capability of the fragments.

Figure 1 depicts this process for a situation in which the TBM and the interceptor have anti-parallel velocity directions (Vt and Vm, respectively), separated by the miss-distance (MD). The fuse is 'looking' in the direction of the TBM under a fixed angle relative to the body of the interceptor, the so-called lean angle. Depending on the fuse properties, it will detect the TBM at a certain range (closing distance) between interceptor and TBM. The fuse needs to process the received information, before the warhead is triggered, causing a certain time delay (Td), during which the closing distance between interceptor and TBM has decreased. The moment the fragmentation warhead detonates, the relative position between TBM and interceptor should be such, that by the time the fragments reach the target, the location of the TBM payload (located in the nose of the TBM) is within the cone of the fragment spray. So, all parameters mentioned above have a strong influence on each other in order neutralize the TBM's warhead.

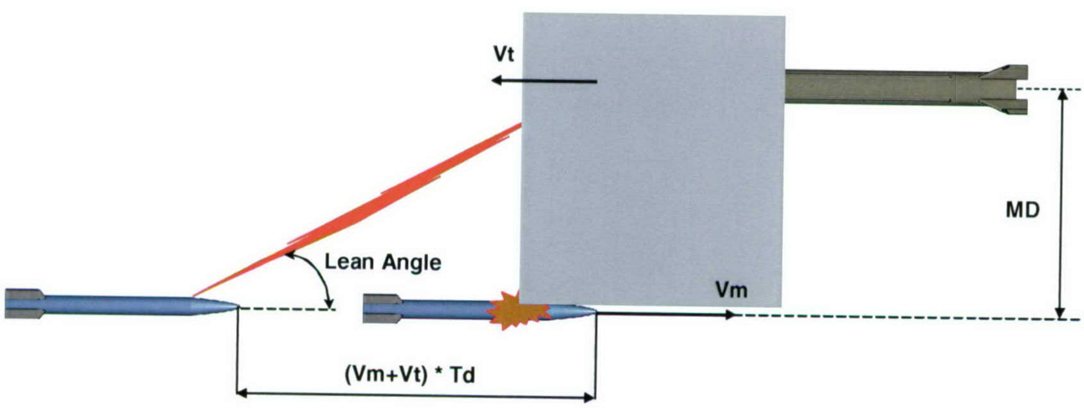


Figure 1 Intercept Geometry between TBM and Interceptor.

2.1 Sensitivity Analysis

Using analytical expressions described in [2], a sensitivity analysis was performed. The fragmentation warhead used in this analysis has a total mass of 83 kg, including a total of 808 Steel fragments with a mass of 45 grams each. Figure 2 shows the fragmentation warhead. The inner part of the warhead contains the explosive (yellow) and the detonator (gray).

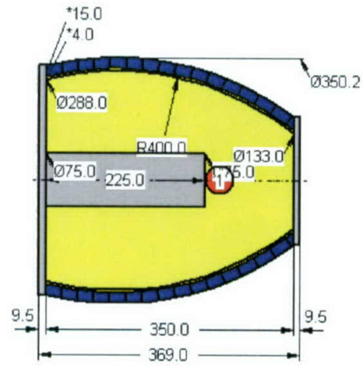


Figure 2 Fragmentaion Warhead with Dimensions in Millimeters.

Based on the physical properties of the warhead, an assessment was conducted of the fragmentation characteristics under static conditions. The fragments are ejected within 39 and 114 degrees, with an average velocity of 1630 m/s, see Figure 3. For the sensitivity analysis, the velocity was assumed to be the same for all fragments.

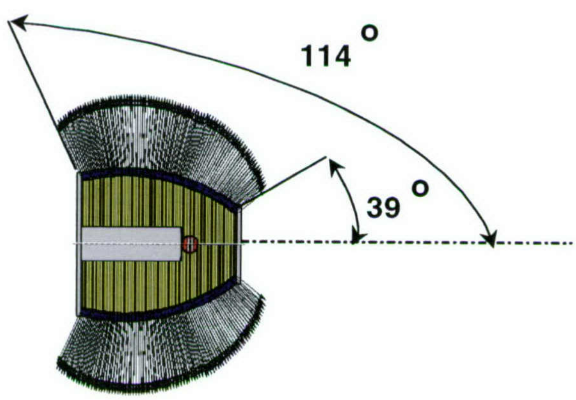


Figure 3 Spray Angles of the Fragmentation Warhead.

For the fuse, a lean angle of 30 degrees was assumed with time delays of 0, 2 ms and 4 ms, respectively. The velocity of the interceptor has been chosen as 1200 m/s, 1400 m/s and 1600 m/s, respectively while the velocity of the TBM was kept at a fixed value of 1000 m/s, throughout. The aim of this analysis was to assess the sensitivity of parameter variations versus the hit distribution of fragments on the cone of the TBM, which houses the payload. No assessment of penetration capability through the payload was made at this stage.

Figures 4 through 6 show the number of fragments that hit the payload section of the TBM for the three chosen interceptor velocities, as function of miss-distance and fuse time delays. The Td = 0 ms case is only a hypothetical situation to assess the upper-bound limit.

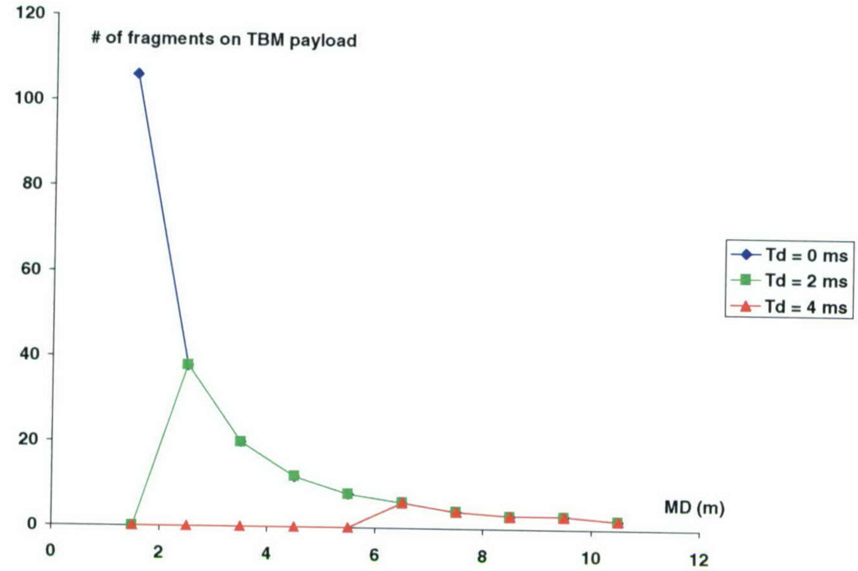


Figure 4 Number of fragments on TBM Payload, with Vm = 1200 m/s and Vt = 1000 m/s.

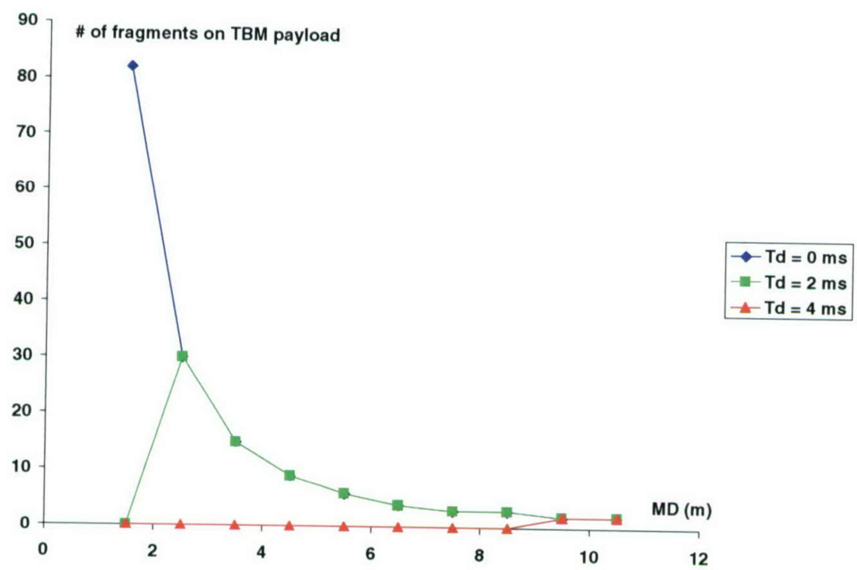


Figure 5 Number of fragments on TBM Payload, with Vm = 1400 m/s and Vt = 1000 m/s.

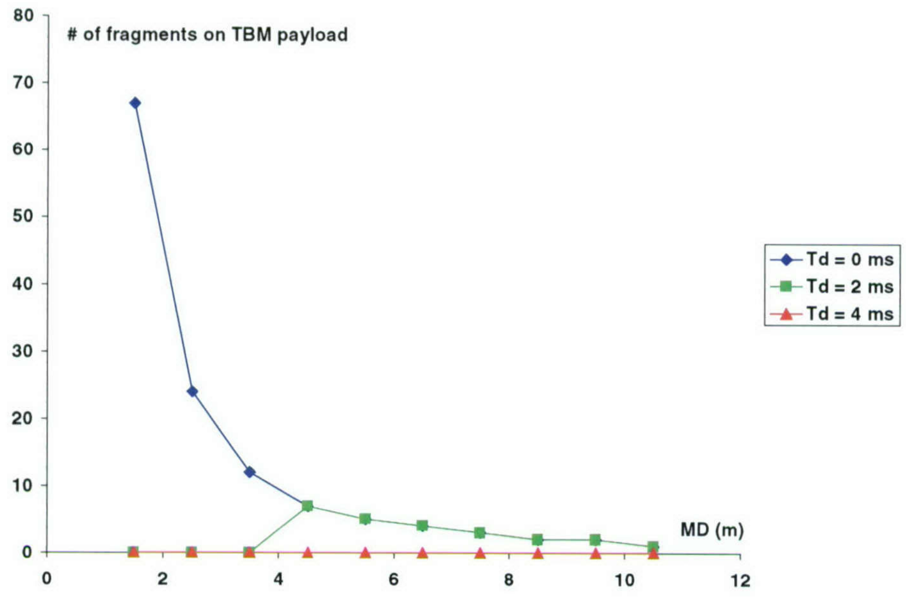


Figure 6 Number of fragments on TBM Payload, with Vm = 1600 m/s and Vt = 1000 m/s.

The figures clearly show that the time delay has a very strong influence on the number of fragments that hit the TBM payload. Figure 7 show the Td = 2 ms situation for the three interceptor velocities considered in this sensitivity analysis.

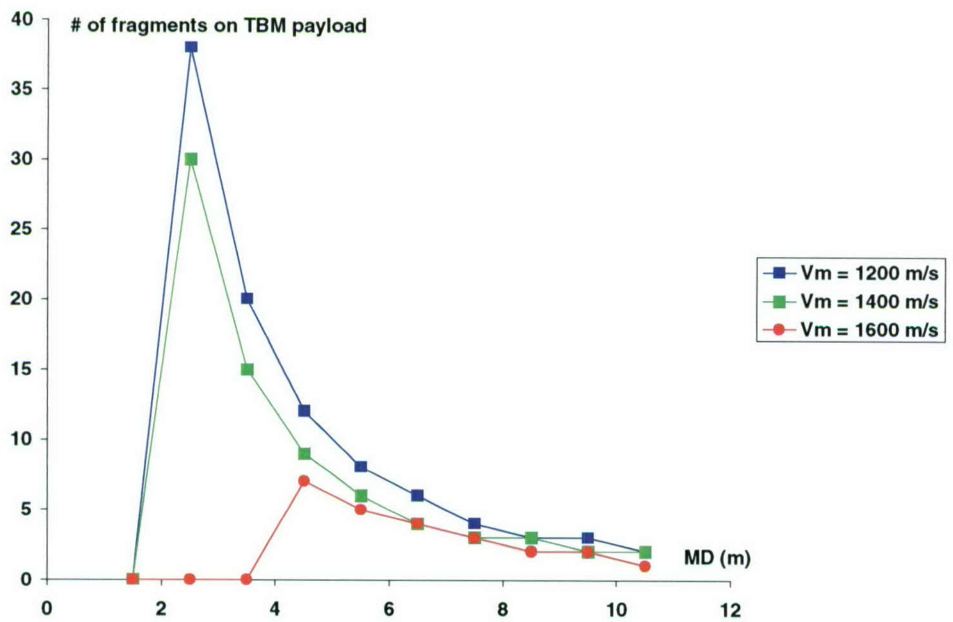


Figure 7 Number of Fragments on TBM Payload, with Vt = 1000 m/s and Td = 2 ms.

Figures 8 through 10 show the locations of the detonation points, measured relative to the nose tip of the TBM and the number of fragments that will hit the payload, given a detonation. The dotted line at the left, represents the earliest moment where the fuse (30 degrees lean angle) would sense the target. Detonation points on that line represent

the hypothetical case for Td = 0 secs. The detonation points more to the right are for Td = 2 ms and Td = 4 ms, respectively.

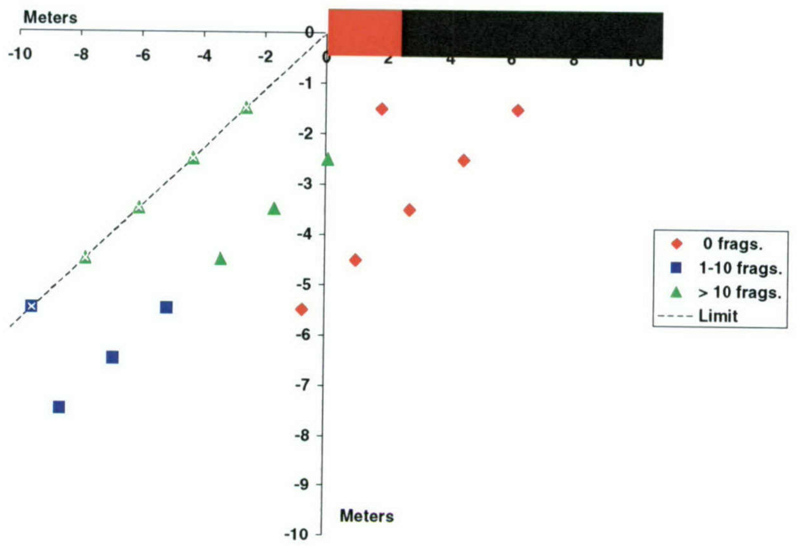


Figure 8 Number of Fragments on TBM payload, with Vm = 1200 m/s and Vt = 1000 m/s.

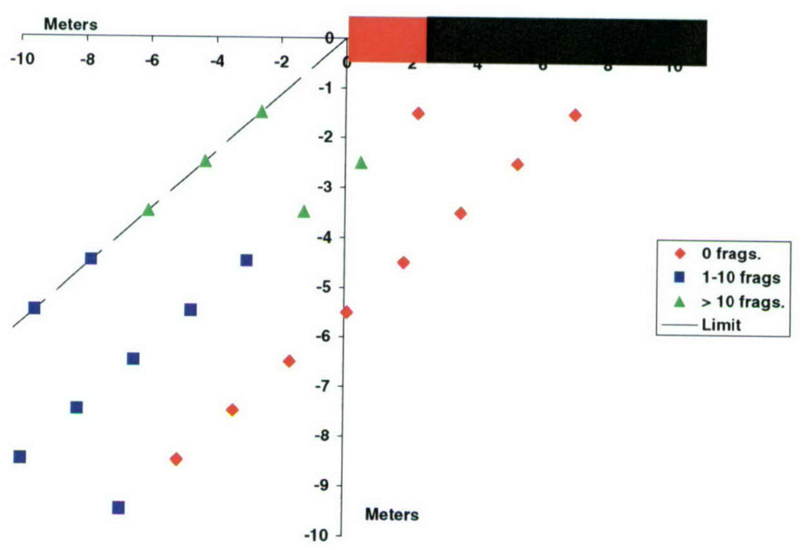


Figure 9 Number of Fragments on TBM payload, with Vm = 1400 m/s and Vt = 1000 m/s.

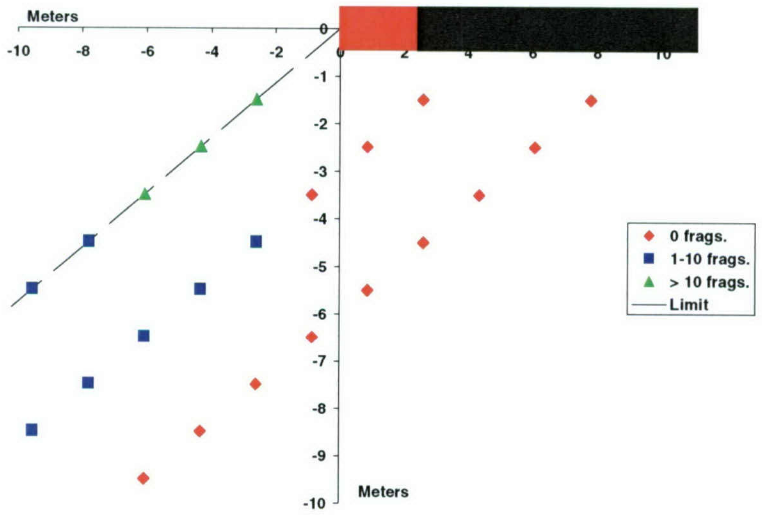


Figure 10 Number of Fragments on TBM payload, with Vm = 1600 m/s and Vt = 1000 m/s..

Figures 8 through 10 clearly show that only a very limited space around the TBM is available for delivering more than 10 fragments on the payload by a fragmentation warhead. Even then, there is no guarantee that the payload has been neutralised. Chapter 4 will address the lethality of the fragmentation warhead, taking the penetration capability of the fragments into account.

3 Hit-to-Kill Interceptor

Another way to defeat TBM payloads is based on the so-called Hit-to-Kill (HTK) principle. The interceptor can be considered as a long rod with sufficient kinetic energy to cut through the payload bay. As a rule of thumb, the total number of submunitions killed by an HTK interceptor can be approximated by the interceptor intersection volume that overlaps any submunition in the payload bay. The overlapping volume of the interceptor strongly depends on the end-game geometry between interceptor and target and their respective velocities, as depicted in Figure 11.

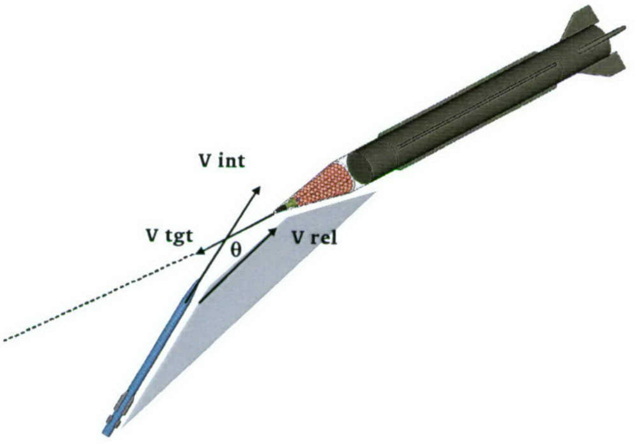


Figure 11 Schematic View of an HTK intercept.

Interceptor and target dimensions and the so-called crossing angle, θ, are the driving parameters. The total surface area, A, projected to the surface of the payload is given by:

$$A = (\pi D^2/4) \cos \theta + LD \sin \theta, \qquad (1)$$

with L and D the interceptor length and diameter, respectively.

For the HTK assessment in this report, a 5.2 m long interceptor, with a 0.25 m diameter was considered. The threat dimensions were identical to the one which was considered for the fragmenting warhead lethality assessment.
Figure 12 shows the projected interceptor area/warhead area ratio for two combinations of interceptor and target velocities, versus the crossing angle θ.

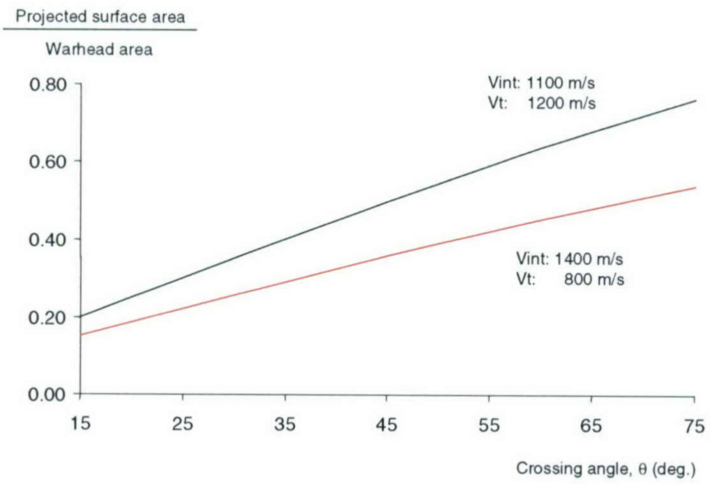


Figure 12 Projected Interceptor Surface Area/Warhead Area Ratio versus Crossing Angle.

Considering the same threat as for the fragmentation warhead assessment and assuming that the relative velocity is pointed at the payload bay, then the maximum volume which is swept away by the HTK interceptor equals approximately 60%-65% of the submunitions. This is under the assumption that the intercecptor has sufficient kinetic energy to cut through the target all the way through. Only the submunitions within the removed volume are considered to be killed. So, hydraulic ram effects, or other forms of energy transportation to neighbouring submunitions are neglected.

4 Lethality of a fragmentation warhead

The payload of the TBM considered in this report, consists of 260 spherical aluminum submunitions (0.11 m diameter) and each submunition containing 0.6 kg chemical agent. Figure 13 shows a three-dimensional representation of the payload.

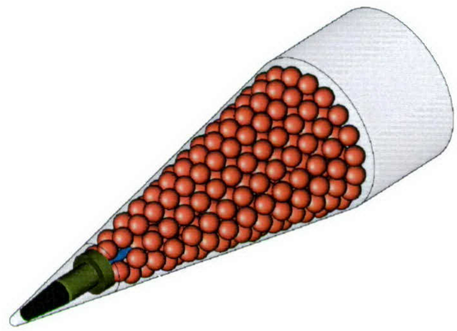


Figure 13 Three-Dimensional Representation of the TBM Payload.

The complete TBM has a length of 11 meters and a 0.9 m maximum diameter. The payload bay is 1.6 meters long.
The same fragmentation warhead as in the previous paragraph was used, however this time the actual ejection velocity was applied to the fragments, rather than an average velocity for all fragments. Figure 14 shows the distribution of the fragments and their velocities over the whole range of ejection angles (39-114 degrees).

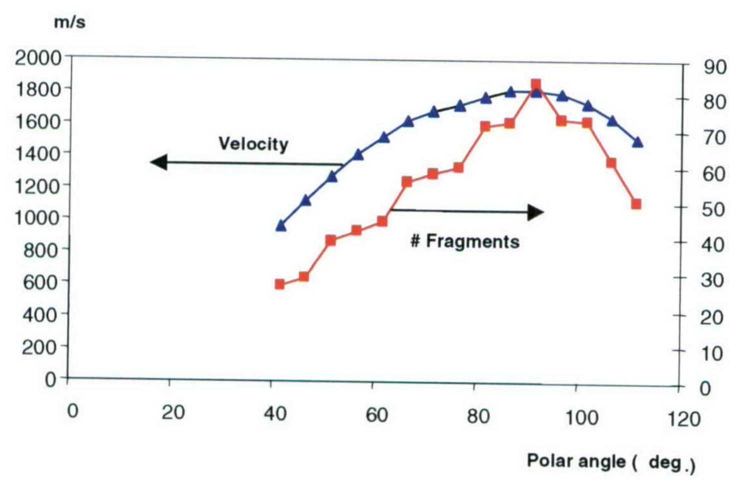


Figure 14 Fragment Distribution of the Fragmentation Warhead.

The following intercept conditions have been considered for the lethality analysis:
Vm: 1400 m/s and 1600 m/s; Vt: 1000 m/s and 1200 m/s; angles between interceptor velocity and target velocity: 0, 20, 30, 45, 110, 120 and 135 degrees, with the head-on situation (Figure 1) being zero degrees and counter clockwise the positive direction of the intercept angles.
For each fragment which strikes the TBM payload section an assessment has been made how deep it penetrates within the payload section and how many submunitions are

perforated. The penetration assessment is based on the so-called Thor penetration equations. Figure 15 depicts this process.

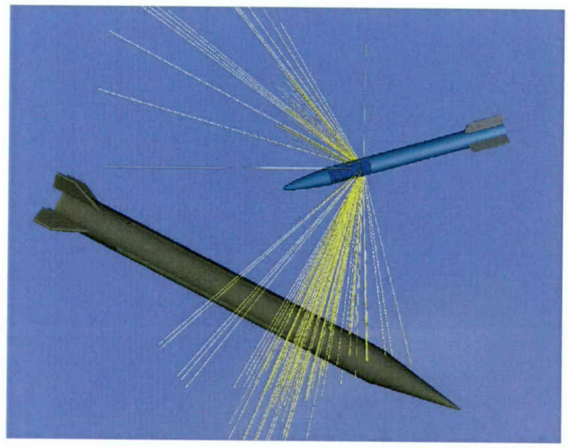


Figure 15 Schematic View of an Intercept by a Fragmentation Warhead.

The kill criterion is based on full perforation of the submunition wall. Damage due to hydraulic ram, blast effects, or fragment shattering effects were not considered.
The sensitivity analysis from the previous paragraph was used to define the positions where most effect might be expected caused by detonation of the warhead. Figure 16 shows the overall results for some of the cases which were considered in this study.

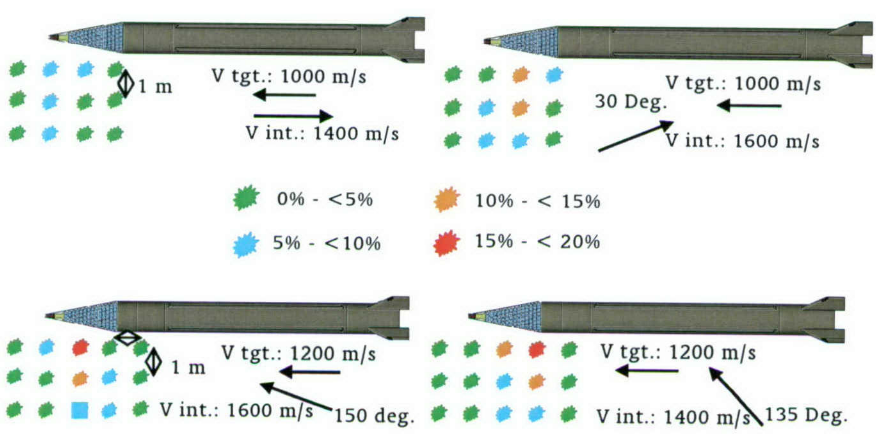


Figure 16 Fraction of Killed Submunitions for the different Burst Positions and Intercept Conditions.

In total some 300 simulations were conducted. Figure 17 shows the distribution of killed submunitions for these simulations.

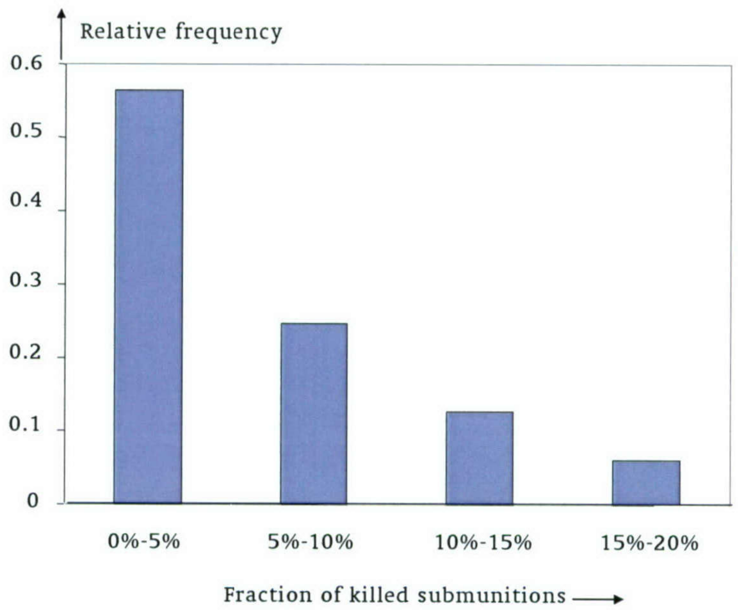


Figure 17 Distribution of killed Submunitions for all Considered Intercpt Situations.

The distribution shows that in less than 50% of the intercepts, more than 5% submunitions are killed and in less than 10% of the intercepts a submunition kill of 15%-20% is achieved. Again, these results are based on perforation capabilities of the fragments through the submunition wall only.

5 Lethality of a Hit-to-Kill Interceptor

The fraction of submunitions killed by a HTK interceptor may increase if so-called lethality enhancers are applied. Lehtality enhancers can be considered as relative heavy fragments, which are expelled just prior before the interceptor hits the target. The ejection velocity of these fragments is in the order of 50 m/s to 200 m/s, which is much lower compared to the fragment velocity of a fragmentation warhead. Since the velocity of the interceptor is an order of magnitude higher, the direction of the lethality enhancer velocities is approximately the same as the direction of the interceptor velocity. Thus, from a target viewpoint, it seems as if, just prior to impact the interceptor increases its diameter, thereby increasing the number of submunitions to be killed. Figure 18 depicts the situation just prior to impact of the interceptor.

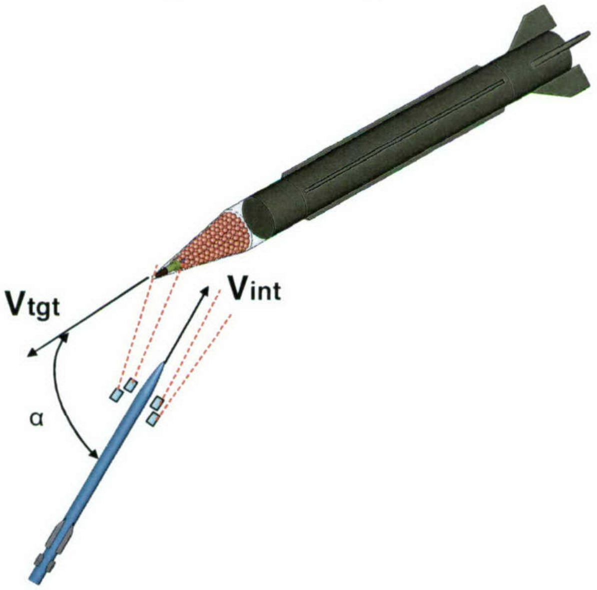


Figure 18 Schematic View of an HTK Interceptor with Lethality Enhancers.

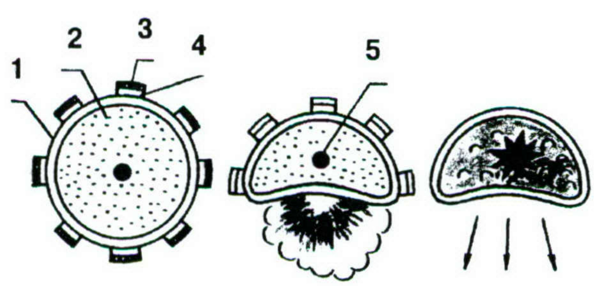
An assessment with 24 tungsten lethality enhancers, each with a mass of 0.22 kg, was conducted. The lethality enhancers were treated as fragments in the same way as was done for the fragmenting warhead (Chapter 4). For interceptor velocities ranging from 1200 m/s to 1400 m/s, target velocities from 1000 m/s to 1200 m/s, and for angles a between 20 degrees and 80 degrees, lethality assessments were conducted. Only those submunitions, which were perforated by the lethality enhancers and which would not have been swept away by the HTK interceptor body were considered as additionally killed submunitions. It appeared that approximately 25% of the submunitions could be additionally killed, resulting in a total of approximately 85% killed submunitions, i.e. 60% by the HTK interceptor body alone (see Chapter 3) and 25% by the lethality enhancers.

6 Fragmentation Warhead versus Hit-to-Kill

From the lethality assessments described in the previous Chapters, it becomes clear that an HTK interceptor is more capable to defeat submunitions than an interceptor with a classical fragmentation warhead. The maximum fraction of submunitions, which might be killed by a fragmentation warhead is in the order of 20%, versus approximately 60% when an HTK intercept takes place. The fraction of killed submunitions by an HTK interceptor, can be further increased to approximately 85% by use of so-called lethality enhancers. These figures should be regarded as first order approximations. For a more detailed analysis other possible damage mechanisms should be taken into account, but were negelected here due to limitations of the applied methodology, such as:

- blast effects from the fragmentation warhead;
- secondary fragmentation due to fragment break-up during perforation;
- possible damage caused by the remainder of the interceptor body after detonation of the fragmentation warhead;
- energy transportation through the submunitions to neighbouring submunitions which are not directly perforated by fragments, or swept away by the interceptor body.

Increasing the the fraction of killed submunitions with a fragmentation warhead might be possible if a so-called aimable warhead is used. This can be achieved by triggering more than one detonator in such a way that most of the fragments are ejected in one particular direction, instead of 360 degrees around the interceptor body axis, as in the case with a classical warhead. Figure 19 shows schematically one of the possible solutions for such an aimable warhead. Before the main detonator is triggered, the wall of the warhwead is deformed by a secondary charge in such a way, that upon detonation of the main charge, the majority of the fragments are ejected in the same direction. Another solution could be a gimballed warhead (Figure 20), pointing in the direction of the target at the moment of detonation. Aimable warheads pose heavy requirements on the fusing and triggering system.



1-envelope;2-plastic charge;3-deforming charge;4-dampers;5-main detonator

Figure 19 Schematic View of a Aimable Warhead.

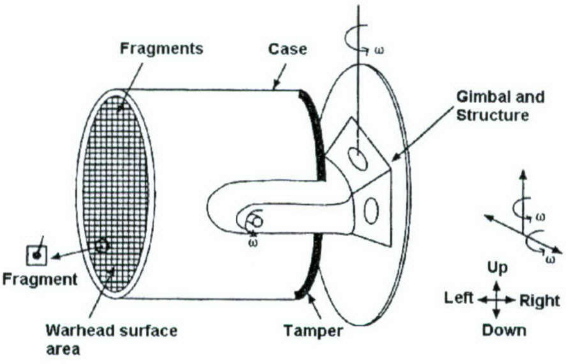


Figure 20 Schematic View of a Gimballed Warhead.

7 Residual ground effects from surviving submuunitions

Once a certain percentage of the submunitions has been neutralized, the question arises what effects are caused on the ground by the surviving submunitions after an intercept. The procedure which was applied is the following:
For different percentages of killed submunitions, the flight trajectories of the remaining submunitions were assessed. Starting point for each submunition was at 20 km altitude, with the intercepted threat coming in under a 55 degree dive angle. At the moment of intercept, the submunitions all have the same velocity, viz. the velocity of the threat. Due to the impact by fragments, or an HTK interceptor, the surviving submunitions will be released with different velocities. The assumption was made that each submunition gets an additional velocity (ΔV), not only along its original flight path, but also in two other directions, orthogonal to the velocity vector of the threat. The magnitude of ΔV was drawn from normal distributions, with σ-values of 50, 100, 150 and 200 m/s, respectively. For the determination of the flight trajectories of the submunitions, only gravity and aerodynamic drag effects were considered. The drag coefficient was taken from various measurements on spheres as function of Mach number, [3]-[6]. The flight path of each individual submunbition was assessed until impact on the ground. As an example Figures 21 and 22 show a side view and a frontal view, respectively of the flight paths of surviving submunitions.

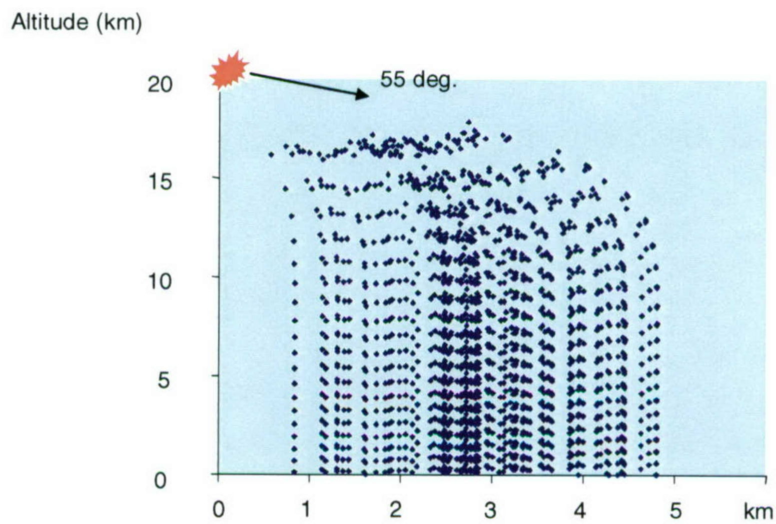


Figure 21 Side View of Surviving Submunitions in Flight at Various Timesteps.

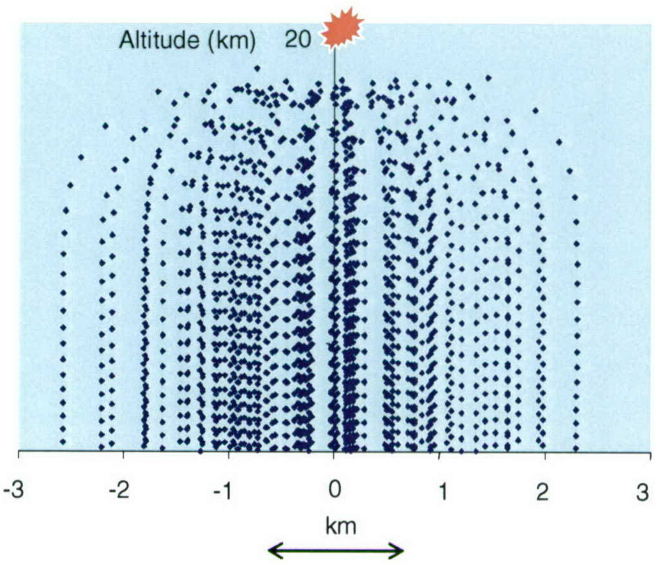


Figure 22 Frontal View of Surviving Submunitions in Flight at Various Timesteps.

Due to the random nature of the velocities for each submunition, the distribution on the ground results in different patterns, expressed in the so-called circular error probable (CEP), which is a circle with a certain radius in which 50% of the submunitions landed. Figures 23 and 24 show two examples of the distribution of surviving submunitions on the ground.

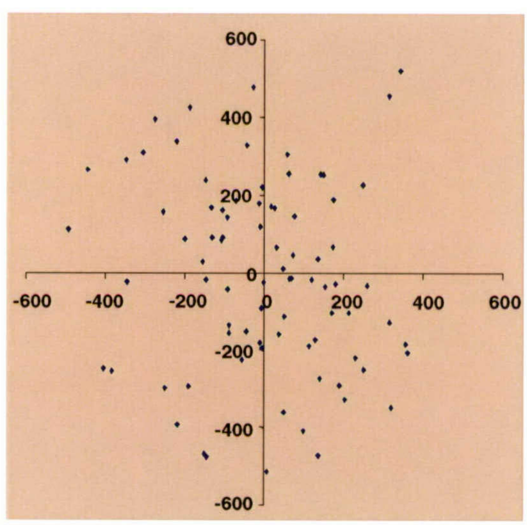


Figure 23 Example of the Distribution (CEP = 260 m) of 35% Surviving Submunitions.

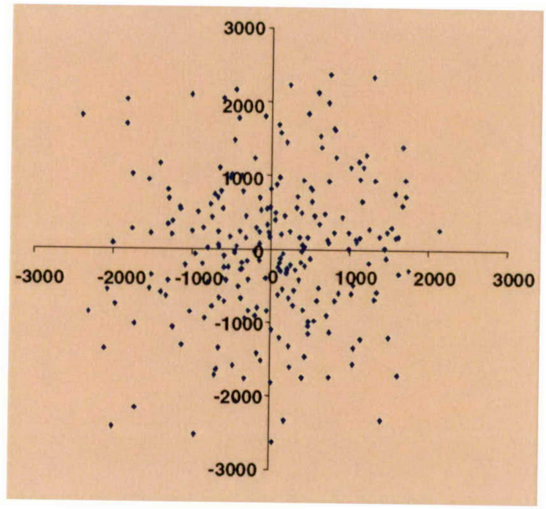


Figure 24 Example of the Distribution (CEP = 1100 m) of 90% Surviving Submunitions.

Next, the contamination on the ground by the surviving submunitions has been assessed. Each submunition is assumed to be filled with 0.6 kg VX chemical agent. Possible losses in effectiveness of the agent due to aerothermal heating during their descent have been negelected. The lethal concentration at which on the average 50% of unprotected populations will not survive (LCt_{50}) is 15 mg.min/m^3, [7]. So, for this study contaminated areas with a LCt_{50} of 15 mg.min/m^3, or higher have been considered to be fatal.

Figure 25 shows the lethal area procduced by a single submunition. A wind velocity of 1 m/s at the surface was assumed. The lethal area for a single submunition appears to be 9800 m^2, with a maximum plume length of approximately 150 m.

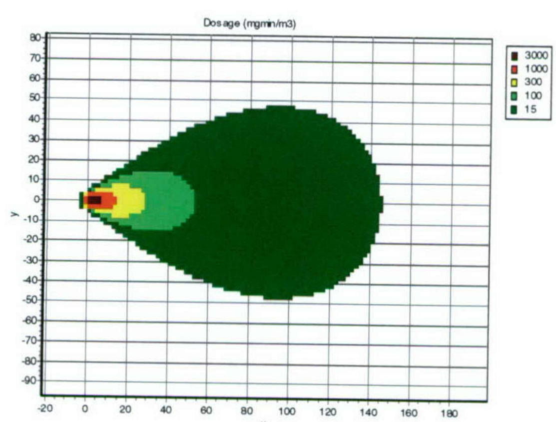


Figure 25 Lethal Area Produced by a Single Submunition, Filled with 0.6 kg VX and LCt_{50} = 15 mg.min/m^3.

As an example, Figures 26 and 27 show the total lethal areas for 90% surviving submunitions, distributed on the ground with a CEP of 270 m and 1100 m, respectively. In these cases the number of submunitions on the ground is large enough to enhance mutual effects between the individual submunitions, causing an increase in lethal area with increasing CEP. At a certain CEP, the submunitions will be separated too much from each other, resulting in a decline of the total lethal area.

Figures 28 and 29 show the same situation as before, however this time for the case that only 35% of the submunitions survived. The figures show that with increasing CEP, 'holes' between the submunitions start to appear, causing a decrease in lethal area.

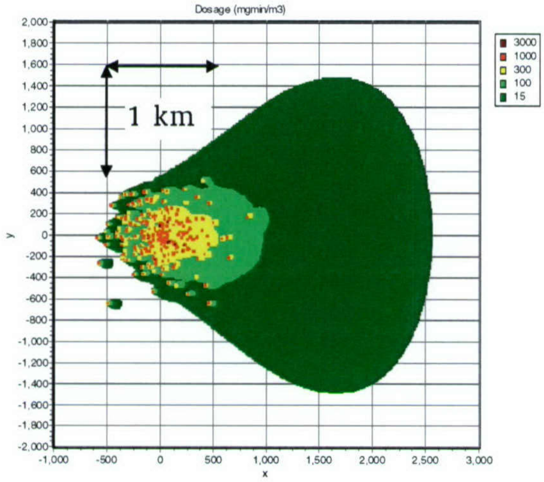


Figure 26 Lethal Area Produced by 90% Surviving Submunitions distributed with a CEP = 270 m.

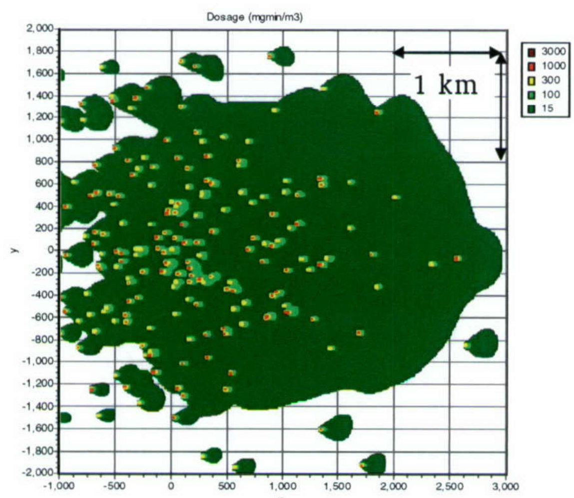


Figure 27 Lethal Area Produced by 90% Surviving Submunitions distributed with a CEP = 1100 m.

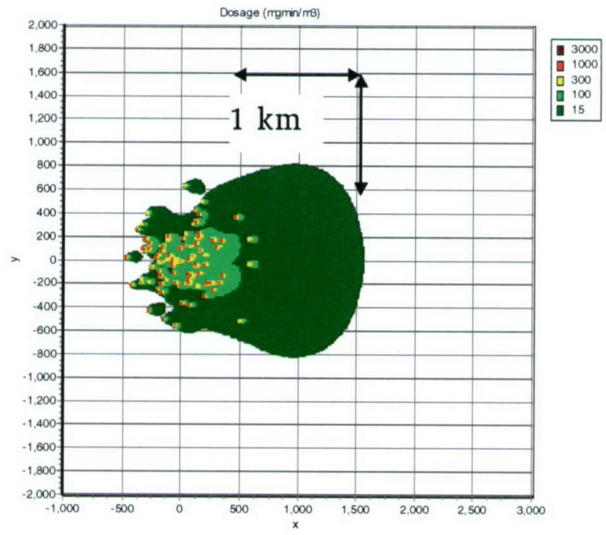


Figure 28 Lethal Area Produced by 35% Surviving Submunitions distributed with a CEP = 270 m.

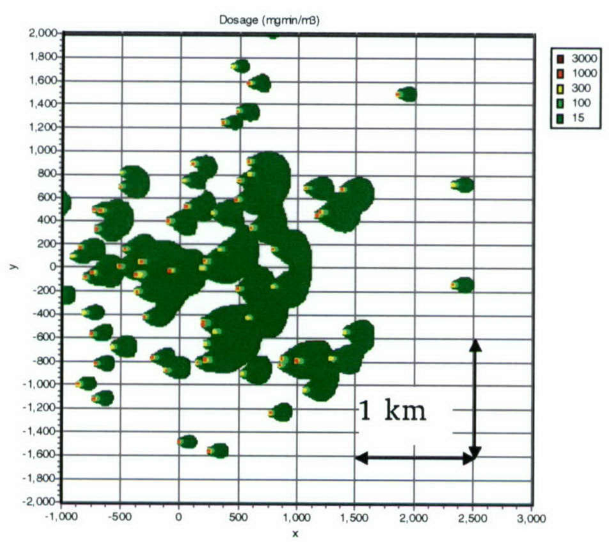


Figure 29 Lethal Area Produced by 35% Surviving Submunitions distributed with a CEP = 1100 m.

So, there is a relationship between the lethal area and the fraction of surviving submunitions, given a certain distribution on the ground (exppressed in CEP). Figure 30 shows this relationship for various CEP values. The dotted line in the figure represents the theoretical limit of the lethal area by multiplying the number of surviving submunitions with the lethal area of an individual submunition, thus neglecting the enhancing effects which occur when these areas show an overlap.

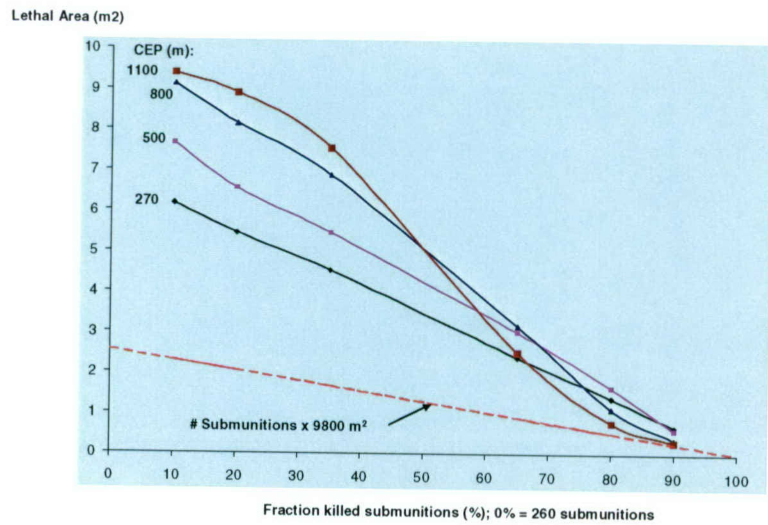


Figure 30 Lethal Area vs. Fraction of Killed Submunitions for Various Distributions on the Ground.

When only a small fraction of the submunitions is killed, the lethal area caused by the surviving submunitions increases with increasing CEP. This tendency disappears when the fraction of killed submunitions increases. Due to the 'holes', as explained above, the lethal area decreases with increasing CEP, because the wider the distribution with a relative small amount of submunitions, the less enhancing effects between the individual submunitions occur. Figure 31 shows this effect again, this time with the CEP along the horizontal axis versus lethal area for various fractions of killed submunitions.

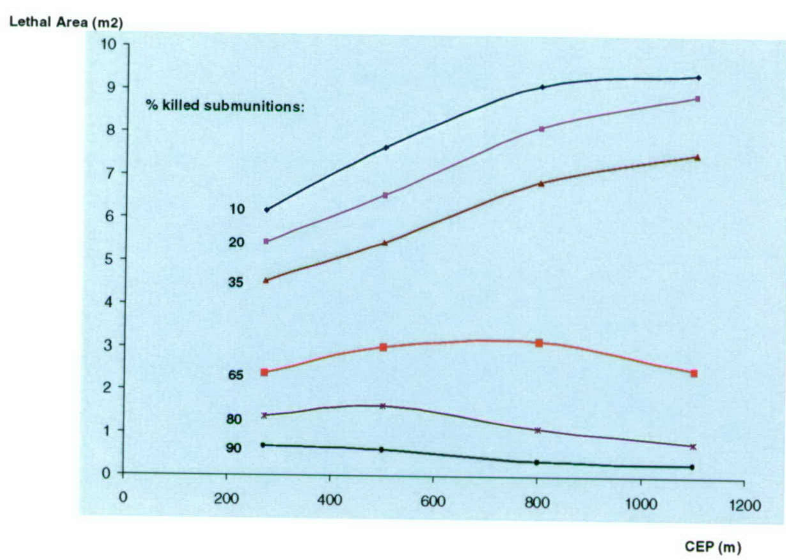


Figure 30 Lethal Area vs. CEP for Various Fractions of Killed Submunitions.

Figure 31 also shows that for 65% or more killed submunitions, there exists a turning point for the CEP, after which the lethal area decreases with increasing CEP. For less than 65% submunitions killed, the maximum lethal area is reached for larger CEP values, while for more than 65% killed submunitions, this occurs for smaller CEP values, relative to this turning point.

8 Conclusions

TBM warheads filled with submunitions are challenging targets for a 100% destruction. Against warheads containing 260 submunitions, an interceptor with a conventional high explosive warhead will destroy approximately 20% of the submunitions at maximum. Some improvement may be obtasined if so-called aimable warheads are considered. A hit-to-kill (HTK) interceptor against the same type of TBM warhead, will destroy approximately 60% of the submunitions. This fraction may be increased this fraction to approximately 85% if lethality enhancers are applied.
Surviving submunitions, containing chemical agents, create a lethal area on the ground, with a total size which is dependent on the distribution of the submunitions. Submunitions lying close to each other create an enhanced effect of their agents and thus, cause a larger lethal area than the sum of the areas of the individual submunitions. If the submunitions are separated far enough from each other, the total lethal area will be no larger than the sum of the lethal areas of the individual submunitions.
The study reported here and the conclusions above, are based on a couple of assumptions, such as:

- For a fragmentation warhead, the effect of the rest of the interceptor body has not been taken into account.
- Submunitions were considered to be killed only, if these are penetrated by fragments, or by the HTK interceptor. So, effects like hydraulic ram, or energy transport to neighbouring submunitions which are not penetrated, are neglected.

To study the validity of these assumptions, a more sophisticated lethality model is needed. An example of such a model is the so-called Parametric Endo/Exo atmospheric Lethality Simulation (PEELS). A request for release of the model was sent out in the autumn of 2002 to the Missile Defense Agency in the U.S. The request was approved and in December 2003 TNO received the model. In the near future PEELS will be used to conduct the same type of simulations as described in this report.

9 References

[1] Haverdings, W.,
Penetration equations for ballistic missile lethality analyses,
TNO report PML 2002-A27.

[2] Lloyd, R.M.,
Conventional warhead systems physics and engineering design,
Progress in Astronautics and Aeronautics, AIAA Book, Vol 179, March 1998.

[3] Hodges, A.J.,
The Drag Coefficient of Very High Velocity Spheres,
Journal of the Aeronautical Sciences, October 1957.

[4] May, A. and Witt, Jr, W.R.,
Free Flight Determinations of the Drag Coefficients of Spheres,
Journal of the Aeronautical Sciences, September 1953.

[5] Charters, A.C. and Thomas, R.N.,
The Aerodynamic Performance of Small Spheres from Subsonic to High Supersonic Velocities,
Journal of the Aeronautical Sciences, October 1945.

[6] Kane, E.D.,
Sphere Drag Data at Supersonic Speeds with Low Reynolds Numbers,
Journal of the Aeronautical Sciences, April 1945.

[7] Defensive Aspects of Chemical and Biological Warfare,
RTO TAR-57.

10 Signature

Rijswijk, July 2005 TNO Defence, Security and Safety

b.a.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

A comparative lethality study between fragmentation warheads and hit-to-kill (HTK) interceptors against ballistic missiles has been conducted. First a sensitivity analysis was performed to determine the influence of some critical parameters for the two lethality mechanisms. Next, a set of intercept geometries was chosen, for which the lethality of fragmentation warheads and HTK-interceptors were compared against a ballistic missile, containing sub-munitions filled with chemical agents. The fraction of killed sub-munitions was used to express the difference between the two lethality mechanisms. Finally, an assessment of the effects on the ground was conducted, caused by the sub-munitions which survived the intercept. The contaminated area which would cause a 50% probability of lethal concentration against unprotected personnel on the ground was used as a measure of effectiveness.

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